APPENDIX A

ALTERNATIVE SLUDGE DEWATERING TECHNIQUES AT WASTEWATER TREATMENT FACILITIES

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1. INTRODUCTION

The typical government-owned wastewater treatment facility serving a U.S. Army or Air Force installation is similar to a small municipal treatment plant. The methods used for treatment and disposal of sludge at municipal plants are also found at military facilities. The handling and disposal of sludge generated at military installations must be consistent with national, state, and local regulations. Dewatering of sludge to reduce the volumes requiring ultimate disposal is a significant part of the overall treatment and disposal process.

2. BACKGROUND

Because of its relative simplicity and economy of operation, many U.S. Army installations use anaerobic or aerobic sludge digestion, followed by conventional sand drying beds for dewatering of sludge before final disposal to a landfill. The designer must weigh the benefits of sand drying beds against the relatively long times required for drying (up to three to four weeks), a continuous requirement for manual sludge removal, and a need for a large, dedicated land area. Moreover, there are operational problems associated with media and underdrain clogging. In addition, outdoor drying beds are vulnerable to adverse weather conditions. Over the years, many improvements in sludge processing techniques have occurred. Among the promising technologies being used successfully in the treatment of sludge at small-scale municipal wastewater treatment plants are wedgewater beds, vacuum assisted drying beds, reed bed systems, and sludge freezing techniques. The Corps of Engineers has been slow to adopt these technologies, but has been studying them intensively as potential sludge dewatering alternatives. The U.S. Army Construction Engineering Research Laboratory (USACERL) has completed several evaluation projects involving wedgewater bed, vacuum-assisted bed, and reed bed technology. Full scale demonstration projects conducted by U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) have shown sludge freezing to be effective.

3. PURPOSE

Two U.S. Environmental Protection Agency (USEPA) Process Design Manuals, (a) *Sludge Treatment and Disposal,* and (b) *Dewatering Municipal Wastewater Sludges,* along with Army TM 5-814-3, *Domestic Wastewater Treatment,* and Water Environment Federation (WEF) Manual of Practice No. 8, contain a detailed discussion of the more commonly used sludge dewatering methods such as drying beds, filter press, centrifuge, etc. The designer is directed to these publications for selection and process design of these systems. The purpose of this ETL is to introduce designers to several newer, less-energy intensive, sludge dewatering techniques which have not been as commonly used, but may be applicable at some Army wastewater treatment plants. They are the wedgewater bed, vacuum assisted bed, reed bed, and sludge freezing beds. Criteria for design and construction of these sludge dewatering techniques at Army and Air Force installations is included. This ETL is intended to promote new information and supplement criteria found in HQUSACE Architectural and Engineering Instructions, Design Criteria. Information contained in this ETL will be used until the criteria can be incorporated into TM 5-814-3, Domestic Wastewater Treatment.

4. WEDGEWATER BED

Wedgewater, or wedgewire beds, are often constructed with an interlocking synthetic filter media placed on a concrete basin with an underdrain system. Polymer is always added to the sludge before placement on the media surface. Wedgewater bed systems can produce sludge with a final solids content of about 8-12 percent in 24 hours and up to 20 percent given additional drying time. Beds are usually uncovered, but may be covered to protect sludge from excessive precipitation. The process is best suited for smaller treatment plants, 1,893 m^3/d (0.5 mgd) or less, and in moderate climates. USACERL has found that wedgewater systems have been used successfully in plants with flows up to 28,387 m^3/day (7.5 mgd)(2). A typical facility consists of the following:

- an outdoor, concrete structure with synthetic media plates
- filtrate collection and drainage system (outlets)
- polymer feed system
- sludge distribution system (inlets)
- washwater system

! Figure 4-1 shows typical sections of a wedgewater drying bed

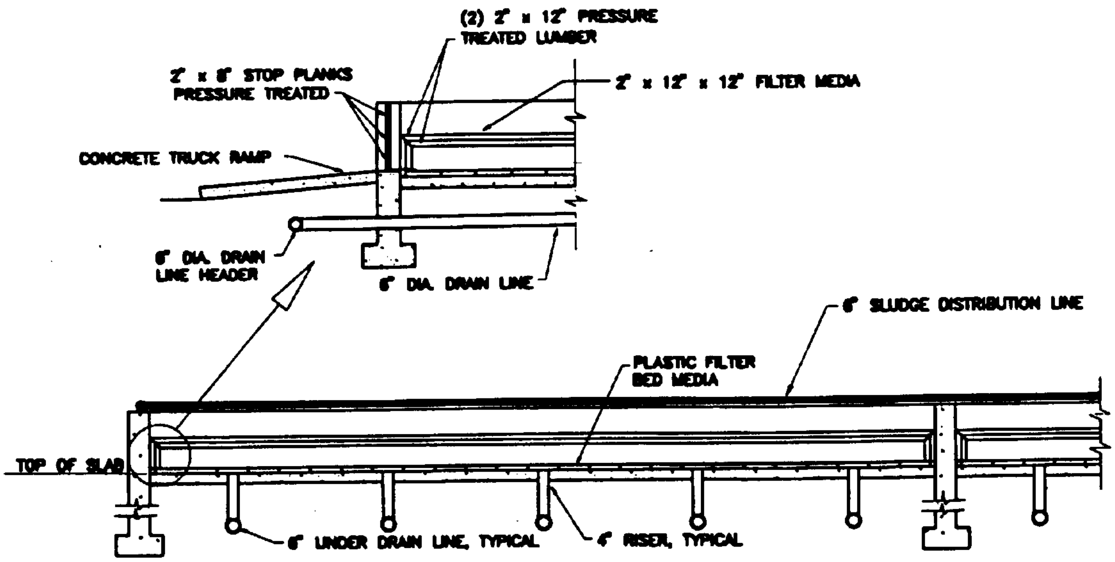

Figure 4-1 Section--Typical Wedgewater Bed

4.1 Recommended Design Considerations:

4.1.1 The main structure should consist of a concrete floor with a drainage system, sidewalls, approximately 0.6 m (2 ft) high, sludge distribution piping, supernatant decanting system, and vehicle entrance for sludge removal.

4.1.2 Manually removable wooden planks are to be installed at the vehicle entrance.

4.1.3 Although most wedgewater operations are uncovered, use of a translucent roof or canopy is recommended in areas with significant precipitation.

4.1.4 Filtrate is drained by gravity through the wedgewater media and over the concrete floor. The floor should be designed with a slope of 0.5 to 1.0 percent to facilitate gravity drainage and avoid solids buildup under the media. Additional pipe drainage system may be installed. As a rule-of-thumb, there should be one drainage outlet for each 2.25 m^2 (25 ft^2) of media.

4.1.5 The media manufacturer's recommendations should be considered for design of a synthetic media dewatering system. The basis for design is the plant's average annual sludge production rate in dry solids (ie., kilograms or pounds per year) and the number of cycles per week that can conveniently be performed. For reliability, a minimum of two beds should be constructed. USEPA states that solids loading rates of 2 to 5 kg/m^2/cycle (0.4 to 1.0 lb/ft^2 /cycle) are typical (6). Adjustments, based on the expected efficiency and effectiveness of the operation, may also be considered. The number of operational cycles per year will vary. While the literature suggests that 24 hour cycle times are acceptable, it is recommended that the design be based on two cycles per week. The design shall allow for downtime for cleaning of beds. Sludge loading rates should be approximately 9.4 L/s (150 gpm).

4.1.6 The general dimensions of each bed should be limited to approximately 7.6 m wide x 15.25m long (25 ft by 50 ft) . This will avoid problems with thermal expansion of the media and with the separation of solids before even distribution of sludge can occur. Additional sludge distribution inlets are also required as compared to conventional sand drying beds.

4.1.7 Supernatant decanter devices are recommended to simultaneously remove water from the surface of the beds.

4.1.8 High pressure washwater systems using treated effluent are recommended for tile cleaning.

4.1.9 The supernatant and filtrate shall be routed back to the headworks, primary clarifier, or aeration basin for additional treatment.

4.2 Operational Issues:

4.2.1 Problems associated with these systems are due to inadequate media cleaning, front-end loader damage, and engineering errors. If the beds are properly designed, constructed, operated, and maintained, the beds will have a long life, and underdrain cleaning will be required only once or twice a year.

4.2.2 A polyurethane blade should be used on the front-end loader bucket. Avoid the use of skid-steering loaders to prevent media damage.

4.2.3 Wedgewater beds have less media clogging if high pressure hoses are used to clean the tiles.

5. VACUUM ASSISTED BED

The vacuum assisted sludge dewatering bed (VADB) uses commercially available equipment to apply a vacuum to the underside of a rigid, porous, media bed on which conditioned sludge has been applied. The theory is that gravity, assisted by the vacuum, draws the water through the media, leaving the dry solids on top. VADB systems are capable of dewatering sludge to a final solids content of about 14 % in 24 hours and 18% or higher in an additional 24 hours. The primary elements of a typical facility are as follows:

- an outdoor, concrete structure with synthetic media plates
- filtrate collection and drainage system
- polymer feed system
- sludge distribution system
- vacuum system
- washwater system
- controls

Figure 5-1 (next page) shows a schematic view of a vacuum-assisted dewatering facility.

5.1 Recommended Design Considerations:

5.1.1 VADBs are generally used for smaller treatment plants, i.e., $\leq$ 7579 m^3/day (2.0 mgd). Sludge is seldom as dry as that removed from sand drying beds. Total solids content varies from site to site and depends on several factors including the basic type of treatment process, sludge conditioning, sludge feed rates, and cycle times.

5.1.2 The bed design is similar to that of a wedgewater bed described previously.

5.1.3 If adverse weather conditions dictate, the beds should be covered.

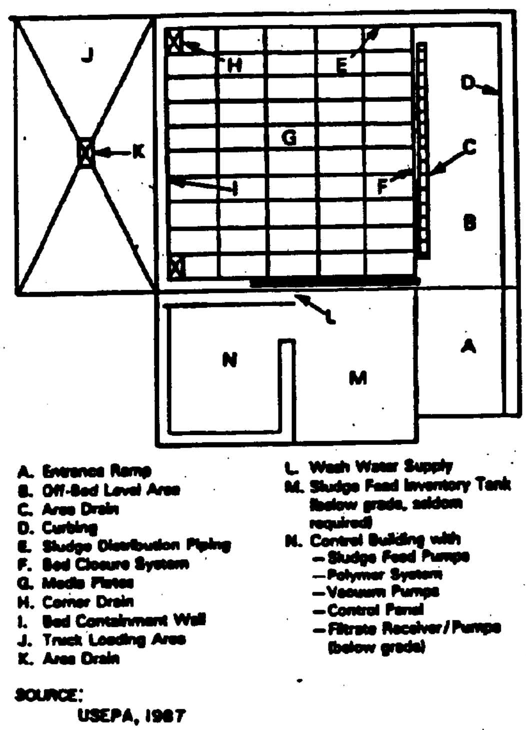

Figure 5-1 Schematic--Vacuum Assisted Sludge Drying Bed

5.1.4 The system equipment manufacturer’s recommendations should be considered for any design of a VADB system. The basis for design is the plant's average annual sludge production rate in dry solids (ie., pounds or kilograms per year) and the number of cycles per week that can conveniently be performed. For reliability, a minimum of two beds should be constructed. USEPA recommends that a solids loading rate of 10 kg/m^2 /cycle (2 lb/ft^2 /cycle) is acceptable (5). Adjustments, based on the expected efficiency and effectiveness of the operation, may be considered. Most VADB designs are based on a 24-hour cycle time. Sludge loading rates should be approximately 9.4 1/s (150 gpm).

5.1.5 Supernatant decanter devices should be installed to simultaneously remove water from the surface of the beds.

5.2 Operational Considerations:

5.2.1 A common complaint of VADB operators is that the sludge is not bladeable in the predicted time and therefore, requires long drying cycles. This problem is due mainly to inadequate drainage caused by media blinding and/or underdrain clogging and to media destruction caused by front-end loaders or epoxy failure.

5.2.2 Plant operators recommend a polyurethane blade be used on the front-end loader bucket to prevent damage. Skid-steering loaders are also inappropriate for this system.

5.2.3 Tile cleaning is more difficult than for wedgewater beds. Media blinding was reported as a major problem with a few existing VADB systems.

5.2.4 VADB produce a faster turnover rate than sand beds.

5.2.5 VADB systems can be operated year-round.

6. REED BED

A new technique being used for sludge dewatering in the United States for the past few years employs the common reed, genus Phraqmites. This treatment method is often called the "reed bed" process since sludge is applied to a pre-designed stand or growth, essentially a bed of reeds. The Max-Planck Institute of West Germany originally conducted research in the late 1960's and early 1970's on the use of the reed bed system to process and dewater wastewater sludges from small wastewater treatment plants. Although the process was originally used for wastewater treatment, it was extended to sludge dewatering in 1980. Using the reed bed system, sludges from wastewater treatment plants are applied to an actively growing stand of a common reed under controlled conditions. The growing reeds derive moisture and nutrients from the sludge, and with time, the rooted plants and the accompanying root ecosystem alter the characteristics of the sludge, resulting in dewatering and improved sludge characteristics. In addition to evapotranspiration, natural environmental processes, such as evaporation and drainage contribute to the moisture loss and dewatering as with conventional sludge beds. Wastewater treatment plants in the northeastern United States have been using reed bed technology successfully for dewatering sludge since the early 1980's.

The primary elements and characteristics of the reed bed process are as follows:

- Bed construction is similar to that of sand drying beds. Often retrofitted sand drying beds are used.

- Excavated trenches are lined with an impermeable material and filled with two sizes of gravel and a top layer of filter sand.

- Reed root stock or small plants are planted in the sand layer and the trenches are flooded to promote reed growth.

- A one meter freeboard above the sand layer is provided to allow for long term sludge storage.

- After plants are well established, stabilized, thickened sludge (3 to 4% solids) is applied to the bed in 10 cm (4 inches) layers at regular intervals.

- Annual harvesting of reeds and their disposal by landfilling, burning, or composting is required.

- Sludge is not removed regularly. Sludge removal cycle time is 6 to 10 years.

Figure 6-1 (next page) shows a typical cross-section of a reed bed.

6.1 Recommended Design Considerations:

6.1.1 A comparison between sludge dewatering with conventional sand beds and the reed bed method shows that reed beds can provide adequate or marginal dewatering for both aerobically and anaerobically digested sludges, if all the existing sand drying beds are converted to reed beds.

6.1.2 The most obvious advantage of reed beds is the elimination of labor for regular sludge removal from sand drying beds. The process also offers many distinct advantages with respect to reduced costs, labor and maintenance. Reed beds can also be constructed from existing sludge drying beds.

6.1.3 Use greenhouses with caution. Greenhouse environments may generate severe heat and drought stress on the reeds.

6.1.4 Higher volumes of aerobically digested sludge may be dewatered than that of the anaerobically digested sludge.

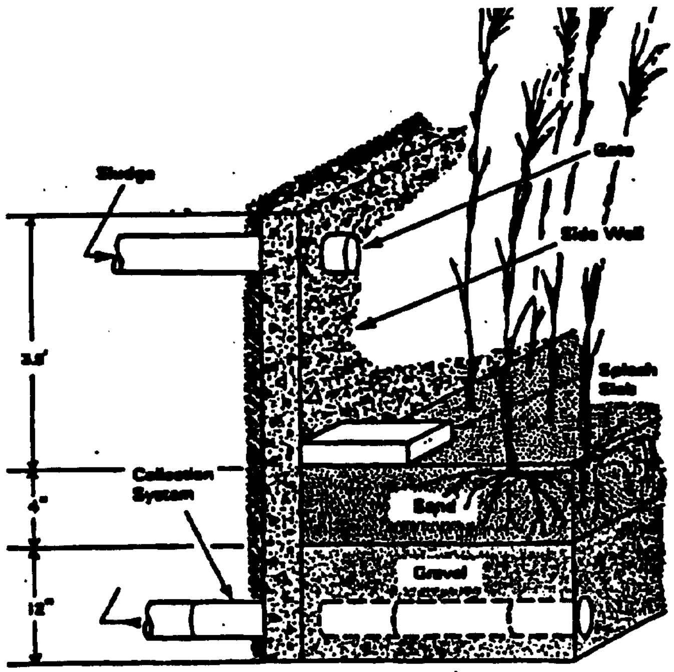

Figure 6-1 Section--Reed Bed

Suggested solids loading rates are as follows (1):

!
For aerobic sludge: 9 to 95 kg/m^2/yr (2 to 20 lbs/ft^2/ yr) USEPA indicates that operational systems in the northeast U.S. average loading rates of 81 kg/m^2/yr (17 lbs/ft^2/yr(5). USACERL studies indicate an average loading rate of 52 kg/m^2/yr (10.9 lbs/ft^2/yr) for systems in the U.S.

!
For anaerobic sludge: 9 to 57 kg/m^2/yr (2 to 12 lbs/ ft^2/yr). USACERL studies indicate an average loading rate of 22 kg/m^2/yr(4.7 lbs/ft^2/yr) for systems in the U.S.

6.1.5 Provide multiple beds to allow for sludge removal and maintenance of beds.

6.2 Operational Considerations

6.2.1 USEPA recommends that thickened sludge (3 to 4% solids) be applied to the beds.

6.2.2 The reeds must be harvested annually and subsequently disposed of in an acceptable manner. Operational problems include aphids and weed growth for younger reeds. Labor for weeding operations should be estimated from one to 10 man-days per year. Estimates vary depending on size of the operation.

6.2.3 Salinity affects the reed height and growth. Maximum recommended salinity is 4.5%.

6.2.4 During freezing months, sludge application is normally stopped and the reeds are harvested.

7. SLUDGE FREEZING BED

A sludge freezing bed is a unit operation that uses natural freeze-thaw to condition the sludge for dewatering. It is most applicable in regions having three months per year of subfreezing temperatures. Freezing beds can be used with conventional drying beds to provide year-round sludge dewatering.

The design incorporates a covered, in-ground containment structure with drainage and ramp access. Drainage may be similar to conventional sand drying beds or synthetic media (wedgewire) systems. During winter months, the sludge is added to the bed in layers. Successive layers are added as the previous layer freezes. At the end of the cold season, the bed is allowed to thaw and drain. Dewatering occurs by the removal of the meltwater by the underdrain system. Once the desired solid/liquid content is achieved, the dewatered sludge is removed by mechanical means. The bed may be used as a conventional covered drying bed during warmer months.

The Cold Regions Research and Engineering Laboratory (USACRREL) was involved in a demonstration project at Fort Greely, Alaska and assisted in freezing bed design for projects constructed at Eielson Air Force Base, Alaska, and Fort McCoy, Wisconsin.

The primary features and characteristics of the freezing bed dewatering system are as follows:

- The facility consists of a basin with an underdrain system where sludge is deposited in layers and allowed to freeze.

! Basins are usually covered to keep precipitation out.

! The process requires no chemical addition. ie., polymers are not required.

! The operation requires no special skills to operate.

Figure 7-1 below shows a typical sludge freezing bed.

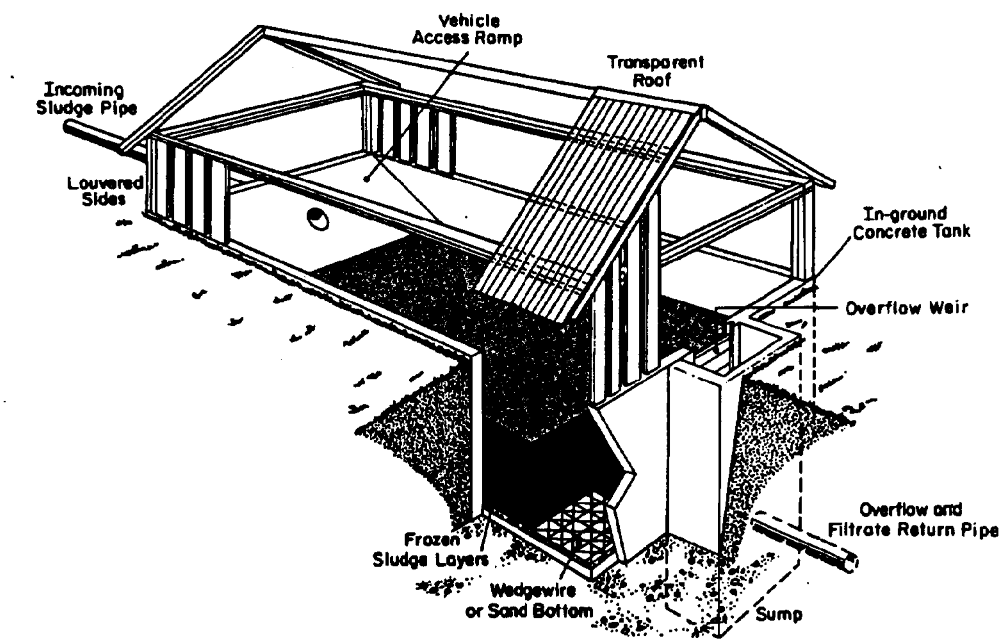

Figure 7-1 Typical Sludge Freezing Bed

7.1 Recommended Design Considerations:

! Freezing is dependent on natural climatic conditions at the proposed site. Any location having three months per year or more of temperatures at or below 0° C may be considered. Sludge freezing is a reliable dewatering method for most of the northern U.S. Figure 7-2 (next page) shows where sludge freezing beds may be used in North America (3).

! Any type of sludge will benefit from the freeze thaw cycle. However, it is recommended that stabilized and thickened

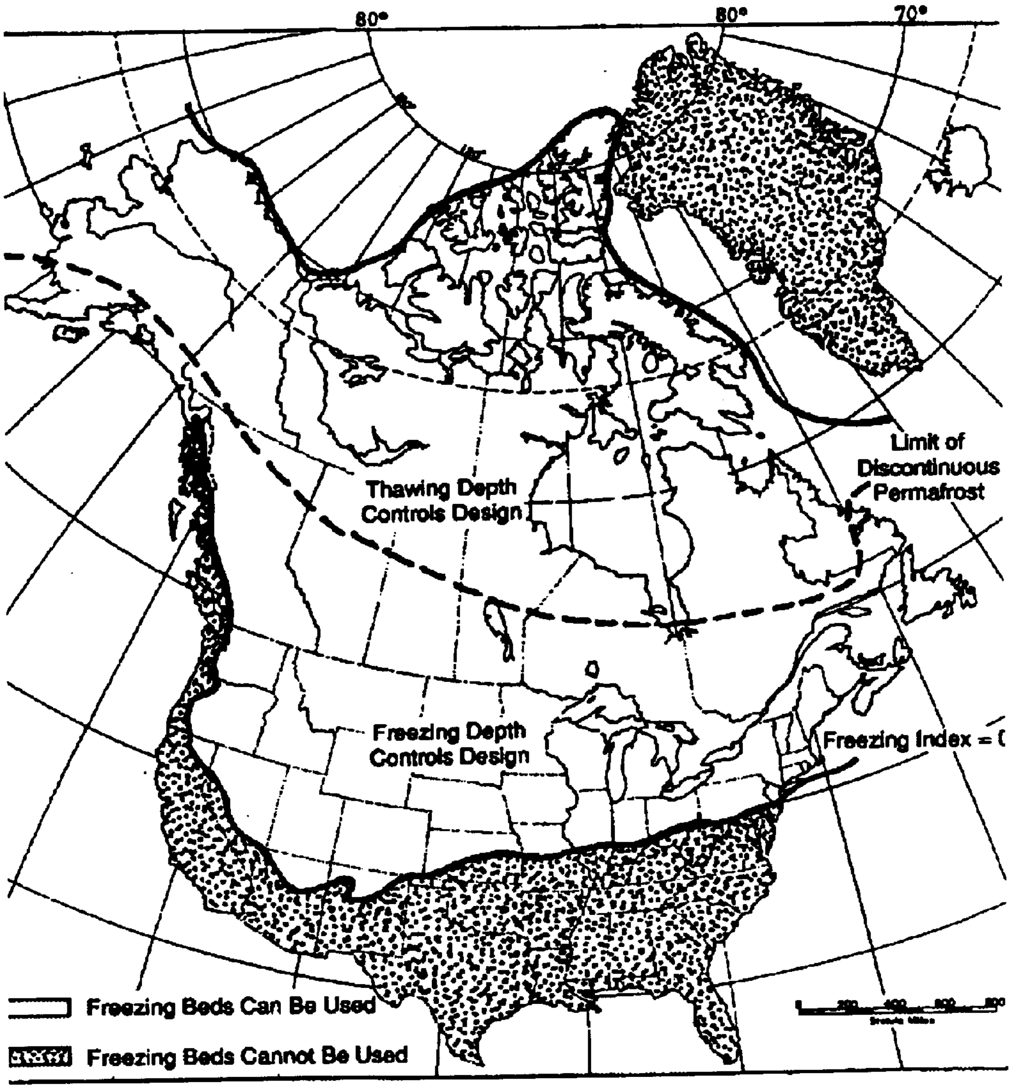

Figure 7-2 Recommended Locations of Sludge Freezing Beds

sludge (3 to 7% solids content) be applied to avoid odor problems, maximize effectiveness, and reduce cost.

- Design the system for the worst case conditions to insure successful performance, ie., warmest winter.

- Consider a pre-engineered metal roof as part of the facility design to protect the area from snow.

Design Procedure:

The size and capacity of the freezing beds depends on the depth of sludge that can be frozen and subsequently thawed a season. In very cold climates, the depth of sludge that can be frozen may be greater than the depth that can be thawed. In that case, the thawing depth will be limiting and should be used for design. The freezing depth ranges from less than 30 cm (12 in) to more than 180 cm (70 in) for most of the northern United States. Martel (3) has suggested that the freezing depth (D_f) be calculated from the following relationship:

$$D_f = P_f (T_f - T_{af}) / D_f L (1/h_c + g/2K_{fs} \qquad \text{Eq. 1}$$

in which P_f = freezing period in hours
T_f = freezing point temperature in °C.
T_{af} = average air temperature during freezing in °C.
D_f = density of frozen sludge
L = latent heat of fusion
h_c = convection coefficient
g = thickness of frozen sludge layer
K_{fs}. = conductivity of frozen sludge

The above equation assumes the freezing bed will be operated as follows:

1. Sludge is applied in layers and each layer is applied when the previous layer has frozen.

2. The temperature of the sludge is at the freezing point when applied to the bed.

3. The surface of the bed is kept free of snow because it would act as an insulator and slow the freezing process.

The first assumption requires that each layer be monitored for completeness of freezing. This may be accomplished manually or automatically. An automatic device for monitoring and control of sludge application has been developed by the Cold Regions Research and Engineering Laboratory (CRREL). Consult CRREL for additional information.

The second assumption, that sludge must be at the freezing point when applied, is difficult to satisfy in practice. Sludges are usually several degrees above freezing. Anaerobically digested sludge, especially, may be above 30° C. The design should allow much of this heat to be dissipated into the atmosphere before or during the application process. However, some melting of the underlying sludge may occur.

Martel also has derived the following equation to calculate the thawing depth ***(Y)***:

$$Y = [(K_{ss} / 2h_c)^2 + 2K_{ss}P_{th} / 2ß]^{1/2} - K_{ss}/2h_c \qquad \text{Eq. 2}$$

in which $ß = D_f L / (T_{at} - T_f + "JI / h_c)$

- K_{ss} = the thermal conductivity of the settled sludge
- 2 = the fraction of settled sludge per unit depth of thawed sludge
- P_{th} = the thawing period
- T_{at} = the average ambient air temperature during the thaw in °C.
- " = the solar absorptance of the sludge
- J = transmittance of the roof material
- ***I*** = the average insolation during the thawing period (Watts/m²)

Some of the physical and thermal properties of sludge are assumed to be equivalent to those of water and ice since the major component of most sludges is water. The suggested values for the variables in the above equations are as follows:

- T_f = 0°C
- D_f = 917 kg/m³
- ***L*** = 93.0 watts•hr/kg
- h_c = 7.5 Watts/m²•°C
- *g* = 0.08 m (Freezing rate will decrease as g as increases.)
- K_{fs} = 2.21 Watts/m•°C

2 = 0.34 for anaerobically digested sludge
0.15 for aerobically digested sludge
K_{ss} = 0.35 Watts/m•°C
" = 0.9
J = 0.9 (transmittance of fiber reinforced polyester)

Values for P_f, P_{th}, T_{at}, T_{af}, and **I** can be obtained from local climatological data.

7.2 Operational Considerations:

! The process is applicable to all types of sludges.

! The operation requires no special skills or equipment.

! The beds are cleaned mechanically rather than by hand.

! The process eliminates separate storage of sludge during winter months.

! Odors associated with unstabilized biological sludges may become a concern during the thawing stage.

! Cost effectiveness of the process will depend on the required area, the cost of land, and the operating costs for multiple winter applications.

FREEZING BED DESIGN EXAMPLE (3)

The design of a sludge freezing bed is demonstrated in the following example. The two sites selected have different natural freezing and thawing energies. Hanover is a typical location in a temperate climate while Fairbanks is a typical location in a subarctic climate. Monthly average air temperatures and insolation data for both sites are shown in Table 7-1 below.

From these data P_f, P_{th}, T_{at}, T_{af}, and **I** and were calculated for each site as follows:

For Hanover,

P_f = January, February, March = 121 days = 2,904 hours
P_{th} = April - November = 244 days = 5,856 hours
T_{af} = [-5.1-9.2-7.3-0.1] / 4 = -5.4°C.
T_{at} = [6+13.4+17.5+20.3+18.4+14.1+7.5+2.4] / 8 = 12.5°C.

I = [202+210+232+249+199+151+98+66] / 8 = 76 W/m^2

TABLE 7-1 Monthly Average Air Temperature and Isolation Data for Fairbanks, AK and Hanover, NH

	Fairbanks, AK		Hanover, NH	
Month (1)	Temperature, °C (2)	Insolation, W/m^2 (3)	Temperature, °C (4)	Insolation, W/m^2 (5)
January	-9.2	70	-23.9	8
February	-7.2	107	-19.7	34
March	-0.1	140	-12.4	103
April	6.0	202	-1.1	182
May	13.4	210	8.7	223
June	17.5	232	14.9	244
July	20.3	249	16.1	210
August	18.4	199	13.1	153
September	14.1	151	7.0	87
October	7.5	98	-3.4	40
November	2.4	66	-15.9	13
December	-5.1	59	-22.8	3

For Fairbanks,

P_f = October - April = 212 days = 5,088 hours
P_{th} = May - September = 153 days = 3,672 hours
T_{af} = [-3.4-15.9-22.8-23.9-19.7-12.4-1.1] / 7 = -14.2°C.
T_{at} = [8.7+14.9+16.1+13.1+7.0] / 5 = 12.0°C.
I = [223+244+210+153+87] / 5 = 183 W/m^2

The final design depth for a potential site will be the lesser of the depths predicted by Equations 1 and 2. Based on the above data and calculations, the freezing design depths (D_f) predicted from Equation 1 for Hanover and Fairbanks are 1.2 m (4 ft) and 5.6 m (18 ft), respectively. The thawing design depths ***(Y)*** predicted from Equation 2 for anaerobically digested sludge (2 = 0.34) for Hanover and Fairbanks are 2.0 m (6.5 ft) and 1.5 m (5 ft), respectively. From these calculations it is apparent that the freezing design depth would be the limiting criterion for Hanover. Conversely, the thawing design depth would be limiting for Fairbanks. The final depths used for design should be 1.2 m (4 ft) for Hanover and 1.5 m (5 ft) for Fairbanks.

For 3,785 m^3/day (1 mgd) plant with a total suspended solids concentration of 200 mg/l in the raw sewage and a 6% solids content in the sludge from the digester or sludge thickener, the size of the freezing bed for each location can be calculated as follows:

Influent solids = 200 mg/l x 3,785 m^3/d x 10^3 1/m^3 x 10^{-6} kg/mg x 365 days/yr

= 276,305 kg/yr

Solids to digester = 0.6 x 276,305 kg/yr = 165,783 kg/yr

Solids to freezing bed = 0.5 x 165,783 kg/yr = 82,892 kg/yr

Sludge volume = 82,892 kg/yr / 0.06 x 1.0 1/kg x 10^{-3} m^3/l = 1,382 m^3/yr

Freezing bed area = 1,382 m^3/yr / 1.2 m/yr = 1,152 m^2 for Hanover

Freezing bed area = 1,382 m^3/yr / 1.5 m/yr = 921 m^2 for Fairbanks

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